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This study addresses the need for a model resolution taxonomy which allows simulation models used in military analysis to be decomposed into a common set of functional areas or dimensions, each with a corresponding measure of detail or resolution, in order to facilitate efforts to revalidate existing models for new applications, integrate existing models to span broader environments, and develop variable resolution models capable of being used in a broad range of applications across varying environments. The model resolution taxonomy and an associated model resolution classification survey is developed based on interviews with subject matter experts, some with broad modeling experience, and others intimately familiar with one of a broad variety of simulation models.

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MODEL RESOLUTION TAXONOMY

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Submitted in partial fulfillment
of the requirements for the degree of

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from the

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ABSTRACT

This study addresses the need for a model resolution taxonomy which allows simulation models used in military analysis to be decomposed into a common set of functional areas or dimensions, each with a corresponding measure of detail or resolution, in order to facilitate efforts to revalidate existing models for new applications, integrate existing models to span broader environments, and develop variable resolution models capable of being used in a broad range of applications across varying environments. The model resolution taxonomy and an associated model resolution classification survey is developed based on interviews with subject matter experts, some with broad modeling experience, and others intimately familiar with one of a broad variety of simulation models.

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EXECUTIVE SUMMARY

The worthy objective of making simulation models more versatile and thus more valuable over a broader range of uses is presently finding expression in three overlapping efforts: the revalidation of existing models for new applications, the integration of existing models to span broader environments, and the development of variable resolution models capable of being used in a broad range of applications across varying environments. All three of these efforts, however, require some means of quantifying model resolution in order to make resolution comparable between models.

The **model resolution taxonomy**, which allows simulation models used in military analysis to be decomposed into a common set of functional areas or **dimensions**, each with a corresponding measure of detail or **resolution**, provides just such a means of making resolution comparable between models.

The taxonomy was developed by first interviewing subject matter experts with broad modeling experience to establish the significant dimensions of simulation models in general. Then subject matter experts intimately familiar with particular models were interviewed and asked to define the dimensions they believed to be significant in their models, as well as an appropriate measure of resolution along each of those dimensions. The results of these interviews were distilled through content analysis to define a common set of dimensions

and a corresponding measure of resolution in each dimension - a **model resolution taxonomy**. A model resolution classification survey was then developed based on this taxonomy.

The **model resolution taxonomy** provides a classification framework whose breadth and depth promise a consistent, objective, quantitative measure of model resolution by dimension unequalled by the classic resolution descriptions of low, medium, and high.

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

As currently practiced, the use of simulation modeling to support military analysis involves identifying specific analysis tasks and constructing models based on those requirements. The tasks must be narrowly defined to give the model developer well defined bounds within which he may make the assumptions necessary to reduce reality to a mathematical model.[Ref. 1]

Unfortunately, these task specific assumptions create a nearly insurmountable barrier to model reuse. Application of a model to an analysis task other than its original narrowly defined one risks violating the assumptions made by the model developer. Thus, model reuse requires extensive revalidation and possible redevelopment, a costly and time consuming proposition, which makes model reuse less attractive as an alternative to developing new models.[Ref. 2]

One solution to this problem is to develop simulation models capable of being used in an environment of varying resolution. In order for one model to be useful in a number of different applications, its attendant submodels must be flexible enough to be used at widely varying levels of realism. Once such a model is accredited over its entire performance range, it may be safely applied to any given analysis task whose specific requirements fall within that relatively wide range by appropriately adjusting the levels of resolution of each submodel.[Ref. 1,3]

A necessary precursor to the development of such variable resolution simulation models is the development of a **model resolution taxonomy** which would decompose model behavior into a set of functional areas or **dimensions** and provide a consistent measure of detail or **resolution** in each dimension,

thus making levels of resolution comparable between models. Such a taxonomy would not only facilitate the development of variable resolution models, but would aid in the analysis of existing models with regard both to validation for new applications and determining suitability for integration. [Ref. 1]

Note that the goal of this taxonomy, to quantifiably and consistently measure model resolution by dimension, is markedly different from that of previous efforts to establish simulation model taxonomies or classification systems such as SIMTAX. SIMTAX, which is representative of much of the work done in model classification, attempts to classify models by three equally weighted categories: the purpose or application of the model, the qualities or capabilities of the model, and the construction or implementation of the model. The **model resolution taxonomy** on the other hand, will focus exclusively on classifying models in terms of resolution by dimension based on the assumption that the principal constraint on model application and the defining factor in model capability is the resolution of the model's dimensions, while implementation is really a secondary issue.[Ref. 4]

B. PURPOSE AND SCOPE

The purpose of this thesis is to develop a **model resolution taxonomy** which will allow simulation models used in military analysis to be decomposed into a common set of functional areas or **dimensions**, each with a corresponding measure of detail or **resolution**.

For example, one dimension might be force composition, and its resolution might be measured on a seven point scale against the reference or **anchoring characterizations** of low, medium, and high resolution listed below.

Low:	only aggregate entities (corps, task force, wing) capable of independent action
Medium:	only aggregate entities (battalion, task unit, squadron) capable of independent action
High:	individual entities (soldiers, vehicles, ships, aircraft) capable of independent action

In scope, this thesis is limited to the initial development of the taxonomy and an associated model resolution classification survey.

C. APPROACH

Since this is a relatively new topic, with little information available in the literature, the primary source of information will be a series of interviews with subject matter experts, some with broad modeling experience, and others intimately familiar with one of a broad variety of simulation models. The objective of these interviews will be to get the subject matter experts to define the dimensions they believe are significant in simulation models in general and in their particular models, and to define an appropriate measure of resolution along each of those dimensions. The results of these interviews will then be analyzed in order to synthesize the multiplicity of divergent conceptualizations about models into a single meaningful system defining a common set of dimensions and a corresponding measure of resolution in each dimension - a **model resolution taxonomy**.

II. METHODOLOGY

A. OVERVIEW

Developing a **model resolution taxonomy** suitable for decomposing simulation models used in military analysis into a common set of functional areas or **dimensions**, each with a corresponding measure of detail or **resolution**, requires a significant amount of insight into a broad variety of models. This insight might be obtainable by first hand analysis of the documentation and code of a representative sample of models, or it can be obtained by interviewing subject matter experts already intimately familiar with these models. Clearly the interview approach is more efficient, and will therefore be used.

Subject matter experts with broad modeling experience will be interviewed to establish the significant dimensions of simulation models in general, as well as to pretest and provide expert review of the interview guideline. Then subject matter experts intimately familiar with particular models will be interviewed and asked to define the dimensions they believe are significant in their models, as well as an appropriate measure of resolution along each of those dimensions. The results of these interviews will be distilled through content analysis to define a common set of dimensions and a corresponding measure of resolution in each dimension - a **model resolution taxonomy**. The model resolution classification survey will then be developed based on this taxonomy.

B. DESIGN OF INTERVIEW GUIDELINE

The interviews will be conducted in a structured interview format. Each expert will be presented with an identical series of predetermined questions. The reason for using the

structured interview format is to offer each expert the same set of possible responses, thus providing more uniform and unbiased responses and allowing greater flexibility in analyzing the interview data.[Ref.5]

Closed format questions are preferred in a structured interview in order to guide responses and eliminate extraneous narrative, thus providing data better suited for analysis. However, the relative newness of the topic and the descriptive (as opposed to normative or cause and effect) nature of the research requires a greater proportion of open-ended questions than would otherwise be desirable in a structured interview. Every effort will be made to convert open-ended questions to closed format questions by anticipating possible responses and providing suitable choices. Where this is not possible, open-ended questions will be focused to guide responses and minimize extraneous narrative.[Ref. 5]

The principal area of response anticipation and guidance is in the definition of significant dimensions. An initial set of significant dimensions applicable to simulation models in general will be constructed based on a review of the available literature [Ref. 4,6,7,8,9], and these will constitute the initial dimension choices in the interview guideline. While this anticipation and guidance of responses does have the potential to bias the interview process by establishing preconceived notions of legitimate responses in the interviewer's mind and predisposing the experts interviewed to give certain responses, the risk is considered marginal. Meanwhile, the interviewees, as subject matter experts, will be given considerable latitude in their responses to elaborate or expound on any topic of relevance, particularly on the open-ended questions.

C. EXPERT REVIEW OF INTERVIEW GUIDELINE

Prior to interviewing subject matter experts intimately familiar with particular models, the interview guideline will be subjected to pretesting and expert review in interviews with subject matter experts well acquainted with a broad variety of simulation models used in military analysis. The purpose of this pretesting and expert review is to ensure that questions in the interview guideline adequately solicit the desired information from the model experts, and that the experts will be able to answer the questions meaningfully. The significant dimensions of simulation models in general are of particular concern in this regard, since they constitute the initial dimension choices in the structured interview guideline and thus frame and guide the responses of the model experts.[Ref. 5]

D. SELECTION OF INTERVIEW CANDIDATES

Model diversity will be the primary consideration in the selection of interview candidates. Since the purpose of the model resolution taxonomy is to provide a framework within which the levels of resolution of different simulation models can be compared, it follows that the sample population of models from which the taxonomy is to be developed must be as varied as possible. However, the sample size will be constrained by the local availability of subject matter experts intimately familiar with particular models. In order to obtain a suitable diversity in the sample population, most models will be represented by a single subject matter expert.

E. DERIVATION OF TAXONOMY

The raw, subjective, open-ended, interview data must be analyzed in order to synthesize the multiplicity of divergent conceptualizations about models into a common set of

dimensions, each with a corresponding measure of resolution, which will constitute the **model resolution taxonomy**. A content analysis, which transforms subjective, qualitative data into an objective, quantitative form by screening it in accordance with predetermined rules through a panel of independent subject matter experts serving as human filters, will be used to perform this analysis [Ref. 10].

Each characterization of low, medium, and high resolution offered by subject matter experts intimately familiar with particular models will be printed onto an individual index card and grouped by applicable dimension.

The complete set of resolution characterization index cards for each dimension will then be independently reviewed by three subject matter experts well acquainted with a broad variety of simulation models used in military analysis.

These experts will determine, based on the resolution characterizations presented on the index cards and their own experience, whether there is a sufficient difference in model resolution in any given dimension to establish a meaningful measure of resolution for that dimension.

For any dimension in which an expert determines a meaningful measure of resolution can be established, that expert will define a reference or **anchoring characterization** of low, medium, and high resolution. The anchoring characterization of low resolution will be at least as low as the lowest resolution characterization on the index cards, without stating that the dimension is not modeled. Likewise, the anchoring characterization of high resolution will be at least as high as the highest resolution characterization on the index cards, while the anchoring characterization of medium resolution will identify a suitable midpoint.[Ref. 11]

Any dimension for which at least two of the three experts provided anchoring characterizations of resolution will be considered significant.

If two of the three possible anchoring characterizations of a given level of resolution for a significant dimension are in agreement, a synthesis of the agreeing characterizations will stand as the anchoring characterization of the given level of resolution for that dimension. Otherwise, all nine of the possible anchoring characterizations of resolution for that dimension will be resubmitted to the three experts for a tie breaking vote on the appropriate anchoring characterizations of each level of resolution for that dimension.

The **model resolution taxonomy** will thus consist of the significant dimensions and their anchoring characterizations of low, medium, and high resolution.

F. MODEL RESOLUTION CLASSIFICATION SURVEY

The model resolution classification survey will be a stand alone document intended to enable subject matter experts intimately familiar with particular simulation models to classify their models in accordance with the **model resolution taxonomy** without any prior experience with the taxonomy. The survey will consist of a brief, readily reproducible, self-explanatory, multiple choice form designed to facilitate dissemination via paper or electronic means, encourage responses, and aid in analysis of results.

III. RESULTS

A. OVERVIEW

The final version of the interview guideline, shown in Appendix A, was the result of pretesting and expert review during interviews with seven subject matter experts well acquainted with a broad variety of simulation models used in military analysis. These experts are listed in Appendix B.

This interview guideline was used in structured interviews with twelve subject matter experts intimately familiar with particular models. These experts and their models are listed in Appendix C, and the resolution characterizations extracted from the raw interview data are presented in Appendix D.

These resolution characterizations were subjected to content analysis which identified the significant dimensions of the **model resolution taxonomy** and defined the anchoring characterizations of low, medium, and high resolution for each dimension. This taxonomy is presented below, and in condensed form in Appendix E. The model resolution classification survey based on this taxonomy is shown in Appendix F.

B. TAXONOMY DIMENSIONS AND ANCHORING CHARACTERIZATIONS

Content analysis of the resolution characterization data defined a **model resolution taxonomy** consisting of the following twenty significant dimensions and their anchoring characterizations of low, medium, and high resolution.

Note that no formal definitions of the significant dimensions, other than the anchoring characterizations of resolution, are provided because individuals using the taxonomy are presumed to have a working definition of each applicable dimension. Rather than requiring these individuals to adopt a formal definition for each dimension and then to classify their models according to those formal definitions,

the taxonomy relies upon the formal anchoring characterizations of resolution to consistently guide the individual's working definition of each applicable dimension in accordance with a common conceptual framework.

1. Force Composition

Low:	only aggregate entities (corps, task force, wing) capable of independent action
Medium:	only aggregate entities (battalion, task unit, squadron) capable of independent action
High:	individual entities (soldiers, vehicles, ships, aircraft) capable of independent action

2. Command and Control

Low:	predetermined actions, uniform performance, no dynamic decisions, no time penalties
Medium:	entity action governed by doctrine based probabilities with decision time penalties
High:	entity action governed by human decision models using available information-perceptions

3. Communications

Low:	perfect communication subject only to possible time penalty
Medium:	track availability of continuous communication path and associated transmission time
High:	track continuous communication path, noise induced distortion, and transmission time

4. Intelligence

Low:	perfect information subject only to possible time penalty
Medium:	automatic fusion of potentially available raw data of predictable reliability
High:	raw data of uncertain reliability from individual sensors

5. Terrain

Low: shorelines of oceans and major inland waters, and political borders
Medium: terrain data (elevation, foliage, cities, roads) affects mobility and detection
High: feature data (bridges, buildings, trees) affects mobility and detection

6. Meteorology

Low: constant parameters affect mobility and detection
Medium: variable parameters (by time or location) affect mobility and detection
High: dynamic physics-based model affects mobility and detection

7. Sensors

Low: constant detection probability

Medium: detection probability varies with range

High: detailed physics models of individual sensors

8. Electronic Warfare

Low: constant parameters affect detection and lethality
Medium: variable parameters (by range or speed) affect detection and lethality
High: detailed physics model affects detection and lethality

9. Weapons Employment

Low: track relative force levels and strengths

Medium: lethality parameters adjusted for force posture, range, terrain
High: individual entities tactically maneuvered to optimize firing solutions, hit probability

10. Weapons Effects

Low: force attrition function of force levels and force strengths
Medium: constant kill probability for each weapon-target pairing
High: detailed physics models of weapon trajectory, impact location, cumulative impact effect

11. Combat Resolution

Low: lanchestrian attrition

Medium: aggregate individual entity kills at battalion, task unit, squadron level
High: track system (mobility, weapon) kills on individual entities

12. Transportation Support

Low: all movements completed at designated times

Medium: aggregate unit's mobility parameters and designated route affect movement rate
High: track individual vehicle movements

13. Supply Support

Low: constant consumption rate for single, representative class of supply
Medium: constant consumption and resupply rates for major classes of supply (food, fuel, ord)
High: consumption and resupply of major classes of supply affected by activity

14. Maintenance Support

Low: all damage permanent, reflected in lethality parameters
Medium: constant repair rate for each class of entity or equipment
High: repair rate is function of damage and available repair resources

15. Engineering Support

Low: predetermined mines and obstacles reflected in mobility and lethality parameters
Medium: constant rate for emplacement-clearing of mines and obstacles affects mobility, lethality
High: dynamic emplacement-clearing of mines and obstacles subject to available resources

16. Medical Support

Low: all casualties dead, reflected in lethality parameters
Medium: constant restoration rate for all casualties
High: casualty handling and restoration is function of injury and available medical resources

17. Training

Low: constant parameters affect mobility, detection, lethality
Medium: variable parameters (by time or entity) affect mobility detection, lethality
High: combat results have dynamic affect on future mobility, detection, lethality

18. Passage of Time

Low: instantaneous table look ups or lanchestrian computations
Medium: discrete events based on entity and mission types
High: real time measured at level corresponding to entity response rates or process durations

19. Campaign Interactions

Low: previous operations have no effect on subsequent operations
Medium: previous operations affect overall force and supply levels for subsequent operations
High: previous operations uniquely affect subsequent force and supply levels of each entity

20. Political Considerations

Low: predetermined roe reflected in detection and lethality parameters

Medium: constant roe constrains entity actions

High: dynamic roe influences entity actions and is influenced by results of actions

C. DEMONSTRATION OF MODEL RESOLUTION CLASSIFICATION SURVEY

The model resolution classification survey was administered to two subject matter experts intimately familiar with the Maritime Prepositioning Force (MPF) Marine Expeditionary Unit (MEU) Slice Offload and Throughput Model, a simulation model for the instream offload of a MEU sized slice of an MPF [Ref. 12]. The results of this trial classification are listed below.

		Classification		
		First	Second	Average
1.	Force Composition	7	7	7.0
2.	Command and Control	4	4	4.0
3.	Communications	1	1	1.0
4.	Intelligence	1	1	1.0
5.	Terrain	1	1	1.0
6.	Meteorology	0	1	0.5
7.	Sensors	0	1	0.5
8.	Electronic Warfare	0	1	0.5
9.	Weapons Employment	0	1	0.5
10.	Weapons Effects	0	1	0.5
11.	Combat Resolution	0	0	0.0
12.	Transportation Support	7	7	7.0
13.	Supply Support	4	6	5.0
14.	Maintenance Support	5	5	5.0
15.	Engineering Support	0	1	0.5
16.	Medical Support	0	1	0.5
17.	Training	0	1	0.5
18.	Passage of Time	6	4	5.0
19.	Campaign Interactions	0	1	0.5
20.	Political Considerations	0	1	0.5

IV. DISCUSSION

A. APPLICATION DEPENDENCY / FORCE OF FOCUS

The expert review of the interview guideline highlighted the dependency of perceived model resolution upon model application. A meaningful **model resolution taxonomy** must provide an absolute framework, independent of application, which will allow simulation models used in military analysis to be decomposed into a common set of dimensions, each with a corresponding measure of resolution. However, the perceptions of the subject matter experts intimately familiar with particular models, which serve as the foundation of the taxonomy and all taxonomical classifications, are clearly conditioned by, and thus dependent upon, the applications in which the models are used.

A related concern was the fact that a model is not necessarily consistent in resolution, even within a single dimension. Within a given dimension a model may deal with some components at a very high level of resolution while other components are handled at a comparatively low level (ie. an amphibious landing model which models landing force artillery pieces individually, but aggregates all naval guns into a single naval gunfire support unit).

These problems were managed by asking subject matter experts to identify their model's **force of focus**, the force with which the model is principally concerned, as distinct from those forces which exist only as necessary to interact with the force of focus. Having the experts define the force of focus served both to illuminate application unique perceptions brought to the models by the experts, and to focus the experts' responses on specific characterizations of resolution for each dimension. Ultimately, the force of focus clarified the nature of the forces to which the absolute,

application independent, measures of resolution by dimension apply.

B. INTERVIEW DATA COLLECTION

The initial objective of the structured interview process was to provide each subject matter expert intimately familiar with a particular model the opportunity to comment on the significance of all twenty-one initial dimension choices, define any additional dimensions they considered significant, and then characterize low, medium, and high resolution for each of the significant dimensions.

However, the maximum effective duration for an interview was one hour, and it was impossible to address all twenty-one initial dimension choices, far less additional dimensions, in a single hour. Meanwhile, most experts were reluctant to characterize all three levels of resolution for any dimension. The most common occurrence was for an expert to characterize the level of resolution he considered his model to represent by describing his model, and then characterize one other, usually opposing, level of resolution by contrast.

Therefore, each interview focused on the dimensions for which the expert indicated his model had the most extreme levels of resolution (high or low), and then dealt with the remaining dimensions as time allowed. The twelve interviews with subject matter experts intimately familiar with particular models consequently produced 112 instances of dimensions being identified as significant, including four additional dimensions, and a total of 216 individual characterizations of resolution. Thus the structured interview process produced adequate data for the content analysis despite its limitations.

C. CONTENT ANALYSIS

The goal of the content analysis was to eliminate the subjective bias inherent in the data collected from interviews with subject matter experts intimately familiar with particular models, in order to distill the divergent conceptualizations regarding model resolution into a single **model resolution taxonomy** by using independent subject matter experts, well acquainted with a broad variety of simulation models used in military analysis, to screen the interview data.

A measure of how successfully the content analysis eliminated the subjective bias of the first set of experts without introducing additional subjective bias from the second set of experts is provided by the fact that 92% of the decisions regarding the significance of a particular dimension were unanimous, and 37% of the decisions regarding the anchoring characterization of a given level of resolution for a significant dimension were unanimous. Moreover, in no case was a separate tie breaking vote required to determine the appropriate anchoring characterization of any level of resolution for any significant dimension.

V. CONCLUSION

The worthy objective of making simulation models more versatile and thus more valuable over a broader range of uses is presently finding expression in three overlapping efforts: the revalidation of existing models for new applications, the integration of existing models to span broader environments, and the development of variable resolution models capable of being used in a broad range of applications across varying environments. All three of these efforts, however, require some means of quantifying model resolution in order to make resolution comparable between models.

The **model resolution taxonomy**, which allows simulation models used in military analysis to be decomposed into a common set of functional areas or **dimensions**, each with a corresponding measure of detail or **resolution**, provides just such a means of making resolution comparable between models. Developed using data from interviews with subject matter experts intimately familiar with one of a broad variety of simulation models, the taxonomy provides a classification framework whose breadth and depth far exceeds the classic resolution descriptions of low, medium, and high. Meanwhile, review provided by numerous subject matter experts well acquainted with a broad variety of simulation models used in military analysis ensured the elimination of subjective bias inherent in interview data, thus promising a consistent, objective, quantitative measure of model resolution by dimension also unequalled by the classic resolution descriptions of low, medium, and high.

The next step in the development of the **model resolution taxonomy** is the testing of the model resolution classification survey based on the taxonomy in order to validate both the survey and the taxonomy by determining whether various simulation models used in military analysis are consistently

classified by subject matter experts intimately familiar with them, and whether such classifications adequately describe and differentiate between the various models.

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APPENDIX A. MODEL RESOLUTION TAXONOMY INTERVIEW GUIDELINE

Model expert background information.

Name: ______________________________

Position: ______________________________

Phone number: ______________________________

Interview date: __________________

Begin interview.

This interview will consist of a series of questions which I will read verbatim. But, your responses do not need to be structured. Feel free to elaborate or expound on any topic, particularly as we move to the more open-ended questions.

The purpose of this interview is to obtain information that will be used to develop a model resolution taxonomy, or classification system. The goal of the taxonomy is to allow simulation models used in military analysis to be decomposed into a common set of functional areas or dimensions, each with a corresponding measure of detail or resolution, and to make levels of resolution comparable between models.

First, I would like to ask you some background questions.

1. What are your areas of expertise? **(Read choices. Check all that apply.)**
    1. __ Operations Research
    2. __ Computer Science
    3. __ Mathematics
    4. __ Physical Sciences
    5. __ Military
    6. __ Other **(Specify.)** ______________________________

2. What simulation models are you intimately familiar with?

    ____

The following background questions deal specifically with the simulation model **(Specify in advance.)** ________________________.

3. What is your relationship to the model? **(Read choices. Check all that apply.)**
    1. __ Sponsor
    2. __ Developer
    3. __ User
    4. __ Other **(Specify.)** ______________________________

4. How many hours per month do you work with the model? **(If not currently working with model, request monthly usage for period of actual use also.)**

____

5. What is the general nature of your use of the model (for example: system design, operational planning, cost and operational effectiveness analysis)?

____

____

6. What results of interest does the model provide you (for example: failure rates, attrition rates, waiting times)?

____

____

____

____

7. For the purpose of this research, the phrase "force of focus" was coined to describe the force with which the model is principally concerned, as distinct from those forces which exist only as necessary to interact with the force of focus. What is the model's force of focus?

____

____

____

____

8. What other forces does the model deal with beside the force of focus?

____

____

____

____

This concludes the background portion of the interview. The remainder of the interview will be devoted to characterizing the detail or resolution of the model with respect to the model's functional areas or dimensions. In order to make the most productive use of our time together, please take a few moments to complete this model resolution summary before we continue. **(Offer model resolution summary. Wait until it is completed.)**

For each of the dimensions you identified as significant with respect to the model's force of focus, I will now ask you to characterize or give an example of low, medium, and high resolution. **(For each dimension marked on model resolution summary, solicit characterization or example of each level of resolution. Do not accept nonexistent as a characterization of low resolution. If time is limited, concentrate on dimensions with extreme values for resolution.)**

___. ____________________

Low: ______________________________

Medium: ______________________________

High: ______________________________

___. ____________________

Low: ______________________________

Medium: ______________________________

High: ______________________________

___. ____________________

Low: ______________________________

Medium: ______________________________

High: ______________________________

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Low: ______________________________

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Medium: ____

High: ____

___. ____________________

Low: ____

Medium: ____

High: ____

___. ____________________

Low: ____

Medium: ____

High: ____

Model Resolution Summary

Please consider the functional areas or dimensions listed below with respect to the previously identified **force of focus**. For each dimension which is **significant** (modeled in some meaningful manner), please indicate the level of detail or resolution by a vertical slash across the adjacent resolution scale.

1. Force Composition
   Low --------------- High
2. Command and Control
   Low --------------- High
3. Communications
   Low --------------- High
4. Intelligence
   Low --------------- High
5. Terrain
   Low --------------- High
6. Meteorology
   Low --------------- High
7. Sensors
   Low --------------- High
8. Electronic Warfare
   Low --------------- High
9. Weapons Employment
   Low --------------- High
10. Weapons Effects
    Low --------------- High
11. Combat Resolution
    Low --------------- High
12. Transportation Support
    Low --------------- High
13. Supply Support
    Low --------------- High
14. Maintenance Support
    Low --------------- High
15. Engineering Support
    Low --------------- High
16. Medical Support
    Low --------------- High
17. Training
    Low --------------- High
18. Morale
    Low --------------- High
19. Passage of Time
    Low --------------- High
20. Campaign Interactions
    Low --------------- High
21. Political Considerations
    Low --------------- High
22. Other: ________________
    Low --------------- High
23. Other: ________________
    Low --------------- High
24. Other: ________________
    Low --------------- High

APPENDIX B. SUBJECT MATTER EXPERTS WITH BROAD EXPERIENCE

* Michael Bailey,	Professor of Operations Research, NPS
William Blatt,	Department of Operations Research, NPS
Daniel Dolk,	Professor of Systems Management, NPS
* William Kemple,	Professor of Operations Research, NPS
* Michael Sovereign,	Professor of Operations Research, NPS
Joseph Sternberg,	Professor of Physics, NPS
Ross Thackeray,	Professor of Physics, NPS

Note: * identifies experts involved in content analysis.

APPENDIX C. SUBJECT MATTER EXPERTS FOR PARTICULAR MODELS

DAMAGE AGGREGATION MODEL (DAG)	
James Esary,	Professor of Operations Research, NPS
EAGLE (EAG)	
Sam Parry,	Professor of Operations Research, NPS
JANUS (JAN, JA2)	
Jude Fernan,	Analyst, TRAC Monterey
Charles Pate,	Analyst, TRAC Monterey
JTLS (JT2, JTL)	
William Cauldwell,	Rolands & Associates Corporation
Edward Kelleher,	Rolands & Associates Corporation
NPS OFF-LOAD MODEL (NOL)	
Keebom Kang,	Professor of Systems Management, NPS
NPS PLATFORM FOUNDATION (NPF)	
Donald Brutzman,	Department of Operations Research, NPS
RESA (RES, RE2)	
Thomas Halwachs,	Professor of Operations Research, NPS
Gary Porter,	Professor of Operations Research, NPS
TACLOGS (TLG)	
David Schrady,	Professor of Operations Research, NPS
TERMAP (TMP)	
Michael Macedonia,	Department of Computer Science, NPS

APPENDIX D. RESOLUTION CHARACTERIZATION DATA

1. Force Composition

	Low	Medium	High
EAG	aggreg entity:bn/brig/div/corps		indiv entity w/test data:tank/soldier
JAN	corps/div/army	indiv soldier/task force	inner/mechanical workings of system
JA2	aggregate companies	indiv soldiers/weapons	weapon system components
JTL			arbitrary sized units from co to div
JT2	aggreg forces - brigades		indiv ships/aircraft/tanks
NOL		track indiv trucks	track indiv vehicle operators
NPF			indiv entities capable indep action
RES	task/battle groups		indiv aircraft/ships
TLG	aggreg all ships into one unit		indiv ships

2. Command and Control

	Low	Medium	High
JAN	preprogrammed action	played off line	entities respond to ea other w/o help
NPF	simplification of fog of war		great variety of channels/sensors
RES	nca level only		indiv cmd modules for ships
RE2	play off line	idealized structure	allows dynamic degradation

3. Communications

	Low	Medium	High
JAN	played off line		
JT2		time penalty to transmit info	
NPF	combine indiv channels		model actual info flow/indiv channels

4. **Intelligence**

	Low	Medium	High
DAG			impact weap ability reach/damage tgt
JTL	complete info on all you see		
		prefused info per avail sensors	
			raw sensor data to be interpreted
JT2		time penalty to fuse sensor data	

5. **Terrain**

	Low	Medium	High
DAG			impact weap ability reach/damage tgt
JAN		woods/bldgs/fences/lakes/roads	
			can destroy terrain(bldgs/trees)
JA2		100m blocks/uniform veg/elev	
			1m blocks/indiv trees(heights/cones)
JTL	lg unif sectors/no grids		
		hexes(7-16km)/elev/trafficbilty	
			100m terrain blocks
JT2	few terrain types		
		hex terrain/boundary affect move	
			affects indiv unit movement/p(detect)
NOL	uniform over entire model		
		road/sea state affects movement	
			terrain varies over length of route
NPF	no terrain but shoreline		
			terrain affects unit interactions
RE2	identify borders/boundaries		
			detailed elev/contour data
TMP	125m btwn elev datums		
			3m terrain grid

6. **Meteorology**

	Low	Medium	High
DAG		impact weap ability reach tgt	
JAN	preprog visib effects on los		
			dynamic rain/snow effects on traffic
JA2		temp/weather effects on los	
			dynamic haze/fog/smoke/battle effects
NOL	sea state affects movement		
		wind/rain/fog affect movement	
NPF	preprog sensor/movement effects		
			live input/measured sensor resp data
RES			current/temp data impinge all sensors
RE2		unif over large areas	
			detailed physics model/real time data
TMP		const param for weather effects	
			weather fn of detailed historic data

7. Sensors

	Low	Medium	High
DAG		impact weap ability reach tgt	
EAG	inferred p(d) per aggreg capab		
			indiv entitied w/indiv tested p(d)
JAN		ea system has sensors w/p(d)	
			track effects of tgt materials/aspect
JA2	adjust lethality coef		
			indiv system sensors w/indiv attrib
NPF	fixed detection parameters		
			real time interaction of sensors
RES			ea platform has indiv sensor suite
RE2	fixed p(d) w/in given range		
			detailed physics model of sonar/radar
TLG	fixed detection parameters		
TMP		model phenomenom to be sensed	
			simul input to real sensor processor

8. Electronic Warfare

	Low	Medium	High
DAG		impact weap ability reach tgt	
RES			ea platform modeled by bandwidth

9. Weapons Employment

	Low	Medium	High
DAG	salvo size determines # hits		
			#rnds/tactics/environ affect p(#hits)
JAN	movement/lethality coef		
			adjust position/LOS of indiv soldiers
JA2			pick locations/adj los during simul
JTL		mean pt impact=aimed pt impact	
			track indiv prob sensor acquisition
NPF	aim in general area = kill		
			model actual tactics
RE2	no control ord load/release		
			indiv guns/bombs modeled
TLG		track # weapon systems used	

10. Weapons Effects

	Low	Medium	High
DAG	salvo size		determines pct damage
			hit value fn hit pos'n fn hit distrib
EAG	cummul effect distrib over unit		
			indiv impact effects per test data
JAN	indiv systems don't fire		
		catastrophic kills or misses	
			plot actual location/effects ea hit
JA2	force/lethality factors		
JT2	lanchester eqn's		
		p(hit)/p(kill) for indiv systems	
			track flight of missle to tgt
NPF	data not based on real tests		
		model results experimental data	
RES	linear fn cumulative impacts		
		lin fn cumul explosive effect	
			nonlin/synerg effect subseq impacts
RE2		plot loc/effect of hit on ship	

11. Combat Resolution

	Low	Medium	High
EAG	attrition per aggreg factors		
			indiv entities killed in engagements
JA2	misses/kills based on p(k)		
		mobility kills/component damage	
JTL	lanchestrian eqn		
		model impact pts w/pk	
			model component probs:load/fire/hit..
JT2	lanchester eqn's		
		p(hit)/p(kill) for indiv systems	
			track flight of missle to tgt

12. Transportation Support

	Low	Medium	High
NOL	don't track indiv trucks		
			track indiv containers on indiv truck
JTL	unit moves where told		
		use truck/rail/ship assets	
			track status of units' organic lift
JT2	assume movement w/o modeling		
			track convoys, incl loading/offload

13. Supply Support

	Low	Medium	High
JAN		fuel/ord constraints/no resup	
			resupply during battle
JA2	no refuel/rearm during simul		
		rearm/refuel in real time	
			rearm/refuel by ammo/fuel type
JTL	few categories/no consumption		
		track consumption by class	
			track consumption of indiv items
JT2	fixed consumption rates		
			consumption rates vary by activity
NOL			track indiv container moves over time
NPF		can monitor supply status	
RE2		must resup weaps/no resup limit	
TLG	const param regardless activity		
			track fuel/ord state by ship/activity

14. Maintenance Support

	Low	Medium	High
JAN	all damage permanent		
		assume some damage repaired	
			damage repaired by repair action
JTL	set fraction always down		
		fixed time to repair	
			repair fn of damage/repair resources
JT2	damaged units replaced		
		fixed repair time	
			repair time varies w/damage/resources
NOL		disting btwn major/minor failure	
			indiv failure rates/failure histories
NPF		can monitor maint status	

15. Engineering Support

	Low	Medium	High
JAN		can emplace/breach obstacles	
			resource limits on emplacement/breach
JA2	preprog obstacles only		
			play engr in real time
JTL	few engr-unit peculiar tasks		
			engr only tasks/limited engr resource
JT2	obstacles have go/no-go effect		
		obstacles affect move/casualties	
			track indiv mines

16. Medical Support

	Low	Medium	High
JAN	all casualties dead	assume some casualties restored	casualties restored by medical action
JTL	set fraction always casualty	fixed time to return to action	restoration fn casualty/med resources
JT2		randomly distrib casualty return	

17. Training

	Low	Medium	High
JAN	preprog engagement ranges/param		dynamic combat/exper effects on param
JA2		function of man in loop	
JT2		param adj-movement/weap effects	

18. Morale

	Low	Medium	High
JT2		param adj-movement/weap effects	

19. Passage of Time

	Low	Medium	High
JA2			runs in real time
JTL	large time step/sparse event set		small (variable) time step(1e-13days)
JT2	effect driven-attrition/logistic		event driven-movement/contact/combat
NOL	track events by day	track hours over 4-5 day period	track events by second
NPF	lanchaster eqn/no time effect	summary event duration distrib	event times modeled per historic data
RES			clock changes do not affect simul
TLG	consumpt'n param indexed by time		consumption param indexed by events
TMP	table lookups make time irrelev		events driven in real time (msec)

20. Campaign Interactions

```
    Low Medium High
JAN played off line
               engagements feed ea other
JTL effects not rippled thru model
        kills recognized thruout model
               logistics constrains subsequent ops
RES little interaction btwn engage
RE2            info from one engage can affect other
TLG start all engage w/full ord load
               ord load fn of previous engagements
```

21. Political Considerations

```
    Low Medium High
JAN no white/civilian/neutral play
        play neutral/roe/casualty limit
RES     preprog roe/alliance rules
```

A1. Level of Human Interaction

```
    Low Medium High
JAN closed model/no man in loop
               open model/dynamic human interaction
```

A2. Anti Submarine Warfare

```
    Low Medium High
JTL fixed observ time to detection
```

A3. Air Campaign

```
    Low Medium High
JTL     aircraft grouped by mission
               indiv aircraft engage
```

A4. Mine Warfare

```
    Low Medium High
JTL damage/time to clear fn of qty
```

APPENDIX E. MODEL RESOLUTION TAXONOMY

1. Force Composition

Low: only aggregate entities (corps, task force, wing) capable of independent action
Medium: only aggregate entities (battalion, task unit, squadron) capable of independent action
High: individual entities (soldiers, vehicles, ships, aircraft) capable of independent action

2. Command and Control

Low: predetermined actions, uniform performance, no dynamic decisions, no time penalties
Medium: entity action governed by doctrine based probabilities with decision time penalties
High: entity action governed by human decision models using available information-perceptions

3. Communications

Low: perfect communication subject only to possible time penalty
Medium: track availability of continuous communication path and associated transmission time
High: track continuous communication path, noise induced distortion, and transmission time

4. Intelligence

Low: perfect information subject only to possible time penalty
Medium: automatic fusion of potentially available raw data of predictable reliability
High: raw data of uncertain reliability from individual sensors

5. Terrain

Low: shorelines of oceans and major inland waters, and political borders
Medium: terrain data (elevation, foliage, cities, roads) affects mobility and detection
High: feature data (bridges, buildings, trees) affects mobility and detection

6. Meteorology

Low: constant parameters affect mobility and detection
Medium: variable parameters (by time or location) affect mobility and detection
High: dynamic physics-based model affects mobility and detection

7. Sensors

Low: constant detection probability
Medium: detection probability varies with range
High: detailed physics models of individual sensors

8. Electronic Warfare

Low: constant parameters affect detection and lethality
Medium: variable parameters (by range or speed) affect detection and lethality
High: detailed physics model affects detection and lethality

9. Weapons Employment

Low: track relative force levels and strengths
Medium: lethality parameters adjusted for force posture, range, terrain
High: individual entities tactically maneuvered to optimize firing solutions, hit probability

10. Weapons Effects

Low: force attrition function of force levels and force strengths
Medium: constant kill probability for each weapon-target pairing
High: detailed physics models of weapon trajectory, impact location, cumulative impact effect

11. Combat Resolution

Low: lanchestrian attrition
Medium: aggregate individual entity kills at battalion, task unit, squadron level
High: track system (mobility, weapon) kills on individual entities

12. Transportation Support

Low: all movements completed at designated times
Medium: aggregate unit's mobility parameters and designated route affect movement rate
High: track individual vehicle movements

13. Supply Support

Low: constant consumption rate for single, representative class of supply
Medium: constant consumption and resupply rates for major classes of supply (food, fuel, ord)
High: consumption and resupply of major classes of supply affected by activity

14. Maintenance Support

Low: all damage permanent, reflected in lethality parameters
Medium: constant repair rate for each class of entity or equipment
High: repair rate is function of damage and available repair resources

15. Engineering Support

Low: predetermined mines and obstacles reflected in mobility and lethality parameters
Medium: constant rate for emplacement-clearing of mines and obstacles affects mobility, lethality
High: dynamic emplacement-clearing of mines and obstacles subject to available resources

16. Medical Support

Low: all casualties dead, reflected in lethality parameters
Medium: constant restoration rate for all casualties
High: casualty handling and restoration is function of injury and available medical resources

17. Training

Low: constant parameters affect mobility, detection, lethality
Medium: variable parameters (by time or entity) affect mobility detection, lethality
High: combat results have dynamic affect on future mobility, detection, lethality

18. Passage of Time

Low: instantaneous table look ups or lanchestrian computations
Medium: discrete events based on entity and mission types
High: real time measured at level corresponding to entity response rates or process durations

19. Campaign Interactions

Low: previous operations have no effect on subsequent operations
Medium: previous operations affect overall force and supply levels for subsequent operations
High: previous operations uniquely affect subsequent force and supply levels of each entity

20. Political Considerations

Low: predetermined roe reflected in detection and lethality parameters
Medium: constant roe constrains entity actions
High: dynamic roe influences entity actions and is influenced by results of actions

APPENDIX F. MODEL RESOLUTION CLASSIFICATION SURVEY

This survey is designed to enable subject matter experts, intimately familiar with particular simulation models, to classify their models in accordance with the **model resolution taxonomy** without any prior experience with the taxonomy.

Please fill in the requested background information. Note that the **force of focus** refers to the force with which your model is principally concerned, as distinct from those forces which exist only as necessary to interact with the force of focus.

Then for each **dimension** or functional area listed below, please circle the number on the adjacent scale which best reflects the **resolution** or detail of your model, with respect to its force of focus, in that dimension.

Please skip any dimensions which are not reflected in your model. Anchoring or reference characterizations of low, medium, and high resolution are listed below each dimension for clarification.

Background Information:

Model name: ______________________________

Your name: ______________________________

Your position: ______________________________

Phone number: ______________________________

Survey date: ______________________________

Number of months of experience with model: ______

Model's force of focus (see introduction):

____

Model Classification:

Dimension Resolution

1. Force Composition Low 1 2 3 4 5 6 7 High

Low: only aggregate entities (corps, task force, wing) capable of independent action

Medium: only aggregate entities (battalion, task unit, squadron) capable of independent action

High: individual entities (soldiers, vehicles, ships, aircraft) capable of independent action

2. Command and Control Low 1 2 3 4 5 6 7 High

Low: predetermined actions, uniform performance, no dynamic decisions, no time penalties
Medium: entity action governed by doctrine based probabilities with decision time penalties
High: entity action governed by human decision models using available information-perceptions

3. Communications Low 1 2 3 4 5 6 7 High

Low: perfect communication subject only to possible time penalty
Medium: track availability of continuous communication path and associated transmission time
High: track continuous communication path, noise induced distortion, and transmission time

4. Intelligence Low 1 2 3 4 5 6 7 High

Low: perfect information subject only to possible time penalty
Medium: automatic fusion of potentially available raw data of predictable reliability
High: raw data of uncertain reliability from individual sensors

5. Terrain Low 1 2 3 4 5 6 7 High

Low: shorelines of oceans and major inland waters, and political borders
Medium: terrain data (elevation, foliage, cities, roads) affects mobility and detection
High: feature data (bridges, buildings, trees) affects mobility and detection

6. Meteorology Low 1 2 3 4 5 6 7 High

Low: constant parameters affect mobility and detection
Medium: variable parameters (by time or location) affect mobility and detection
High: dynamic physics based model affects mobility and detection

7. Sensors Low 1 2 3 4 5 6 7 High

Low: constant detection probability

Medium: detection probability varies with range

High: detailed physics models of individual sensors

8. Electronic Warfare Low 1 2 3 4 5 6 7 High

Low: constant parameters affect detection and lethality

Medium: variable parameters (by range or speed) affect detection and lethality

High: detailed physics model affects detection and lethality

9. Weapons Employment Low 1 2 3 4 5 6 7 High

Low: track relative force levels and strengths

Medium: lethality parameters adjusted for force posture, range, terrain

High: individual entities tactically maneuvered to optimize firing solutions, hit probability

10. Weapons Effects Low 1 2 3 4 5 6 7 High

Low: force attrition function of force levels and force strengths

Medium: constant kill probability for each weapon-target pairing

High: detailed physics models of weapon trajectory, impact location, cumulative impact effect

11. Combat Resolution Low 1 2 3 4 5 6 7 High

Low: lanchestrian attrition

Medium: aggregate individual entity kills at battalion, task unit, squadron level

High: track system (mobility, weapon) kills on individual entities

12. Transportation Support Low 1 2 3 4 5 6 7 High

Low: all movements completed at designated times

Medium: aggregate unit's mobility parameters and designated route affect movement rate

High: track individual vehicle movements

13. Supply Support Low 1 2 3 4 5 6 7 High

Low: constant consumption rate for single, representative class of supply

Medium: constant consumption and resupply rates for major classes of supply (food, fuel, ord)

High: consumption and resupply of major classes of supply affected by activity

14. Maintenance Support Low 1 2 3 4 5 6 7 High

Low: all damage permanent, reflected in lethality parameters

Medium: constant repair rate for each class of entity or equipment

High: repair rate is function of damage and available repair resources

15. Engineering Support Low 1 2 3 4 5 6 7 High

Low: predetermined mines and obstacles reflected in mobility and lethality parameters

Medium: constant rate for emplacement-clearing of mines and obstacles affects mobility, lethality

High: dynamic emplacement-clearing of mines and obstacles subject to available resources

16. Medical Support Low 1 2 3 4 5 6 7 High

Low: all casualties dead, reflected in lethality parameters

Medium: constant restoration rate for all casualties

High: casualty handling and restoration is function of injury and available medical resources

17. Training Low 1 2 3 4 5 6 7 High

Low: constant parameters affect mobility, detection, lethality

Medium: variable parameters (by time or entity) affect mobility detection, lethality

High: combat results have dynamic affect on future mobility, detection, lethality

18. Passage of Time Low 1 2 3 4 5 6 7 High

Low: instantaneous table look ups or lanchestrian computations

Medium: discrete events based on entity and mission types

High: real time measured at level corresponding to entity response rates or process durations

19. Campaign Interactions Low 1 2 3 4 5 6 7 High

Low: previous operations have no effect on subsequent operations

Medium: previous operations affect overall force and supply levels for subsequent operations

High: previous operations uniquely affect subsequent force and supply levels of each entity

20. Political Considerations Low 1 2 3 4 5 6 7 High

Low: predetermined roe reflected in detection and lethality parameters

Medium: constant roe constrains entity actions

High: dynamic roe influences entity actions and is influenced by results of actions

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